Seasonal Occurrence of Postharvest Dried Fruit Insects and Their Parasitoids in a Culled Fig Warehouse

J. A. JOHNSON, K. A. VALERO, M. M. HANNEL, AND R. F. GILL

Horticultural Crops Research Laboratory, USDA–ARS, 2021 South Peach Avenue, Fresno, CA 93727

J. Econ. Entomol. 93(4): 1380–1390 (2000)

ABSTRACT Parasitoids of dried-fruit insects were surveyed at a culled fig warehouse in Fresno, CA. Three parasitoids of pyralid larvae were found: *Habrobracon hebetor* (Say), *Venturia canescens* (Gravenhorst), and at least one species in the genus *Goniozus* Förster. Two parasitoids of pyralid pupae also were noted: *Mesostenus gracilis* (Cresson) and a new species of *Psilochalcis* Keifer. The latter is a new host association. Several beetle parasitoids were present, including *Anisopteromalus calandrae* (Howard), three species of *Cephalonomia* Westwood, *Laelius centratus* (Say), and *Cerchysiella utilis* Noyes. *C. utilis*, a parasitoid of driedfruit beetle, *Carpophilus hemipterus* (L.), is a new record for California. Most activity by parasitoids (detected by yellow flight traps) occurred directly above the fig mass. Pyralid parasitoids exhibited two peaks of seasonal activity; one in late summer through early fall, shortly after new figs were brought into the warehouse, and one in the spring. *H. hebetor* generally attacked older host larvae, whereas *V. canescens* equally attacked older and younger larvae, indicating that these two parasitoids may coexist by exploiting different portions of the host population. *H. hebetor* was active throughout the winter, suggesting that winter release of *H. hebetor* could be used to control diapausing pyralid populations in dried fruit and nut storage areas.

KEY WORDS Pyralidae, stored products biological control, parasitoids

California leads the world in the production of dried fruits, with >500,000 tons of raisins, prunes, dates, and figs produced each year, worth >$500 million (USDA 1998). Several insect species can become serious postharvest pests on dried fruits produced in California (Simmons and Nelson 1975). Of particular concern to most processors is Indianmeal moth, *Plodia interpunctella* (Hübner); driedfruit beetle, *Carpophilus hemipterus* (L.); and sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.). Currently, control practices for these insects rely on scheduled fumigation with methyl bromide or hydrogen phosphide. After action taken by the Parties of the Montreal Protocol, methyl bromide was designated an ozone depleter (UNEP 1992). Although the U.S. Clean Air Act would have eliminated production and importation of methyl bromide in this country by 1 January 2001, recent legislation brought the U.S. phaseout of methyl bromide in line with that of the Montreal Protocol, with nearly complete reduction scheduled for the year 2005. Insect resistance to hydrogen phosphide has been documented in other commodities (Zettler et al. 1989), and the U.S. EPA is considering increased restrictions on the use of this fumigant (USEPA 1998). Consequently, concern over the restriction of these fumigants has generated interest in developing alternative treatment methods. One possibility that is being explored in other commodities is the use of natural enemies (Brower et al. 1995, Schöller et al. 1997).

Substandard or culled figs (≈7–15% of total California production; USDA 1998) that are not to be used for human consumption are often warehoused and sold as cattle feed. Figs brought to culled fig warehouses in the San Joaquin Valley may be from any part of the fig-producing region of California and are often infested with insects. Because little or no attempt is made to control infestations, impressive populations of postharvest insect pests, along with their natural enemies, develop in the culled figs. Because the insects present in postharvest figs are also common in other dried fruit and nut commodities, the culled-fig warehouse presents an opportunity to survey the natural enemies present in dried fruit insect populations, particularly insect parasitoids of pyralids, to make observations concerning their seasonality and to isolate and culture promising species for use in subsequent biological control studies. The results may be used to incorporate parasitoids into a postharvest insect pest management strategy for the various dried fruit and nut commodities produced in California. This article presents the results of 5 yr of such study.

Materials and Methods

Description of Study Site. The culled-fig warehouse was located in Fresno, CA, in an area of light industry and residences. The facility consisted of an enclosed, unheated warehouse of ≈680 m^2 and a covered, open-

This article presents the results of research only. Mention of a proprietary product does not constitute an endorsement or recommendation by USDA for its use.

sided, 920-m^2 raised dock. Culled figs were received sometime after the first harvest, usually beginning in August and continuing through October. Figs arrived in wooden bins (1.3 by 1.3 by 1.3 m, or 1.3 by 1.3 by 0.7 m) and were stored in the warehouse or on the dock until they could be dumped from the bins onto a large pile in the center of the dock. Sale and distribution of the figs as cattle feed began soon after receipt and continued throughout the year. During summer, water was often added to the fig mass to maintain suitable moisture content. No insect controls were used other than occasional insecticide applications along the perimeter of the warehouse for ant control. Generally, there were some figs still present when new figs arrived, but occasionally all figs were sold before new figs were received. Approximately 1,950 metric tons of culled figs was handled each year. We obtained records from the California Fig Advisory Board for substandard fig receipts and sales and estimated the tonnage of figs present within the warehouse for each month of the study.

Pheromone Trapping of Pyralids. We used Pherocon 1C wing traps (Zoecon, Palo Alto, CA) baited with commercial Indianmeal moth pheromone lure (Consep, Bend, OR) to monitor adult pyralid activity. The lure attracts males of five pyralid species—Indianmeal moth; Mediterranean flour moth, *Ephestia kuehniella* Zeller; tobacco moth, *Ephestia elutella* (Hübner); almond moth, *Cadra cautella* (Walker); and raisin moth, *Cadra figuliella* (Gregson). Six traps were used; one was located in the warehouse area and five were placed on the dock. To avoid destruction of the traps from machinery, the traps on the dock were hung from roof rafters ≈5 m from the surface of the dock. We used double-looped wire hooks and a telescoping pole to place and remove the traps (Curtis and Clark 1984). From late March until November, traps were checked every week and the sticky bottoms were replaced when necessary. During the winter, when moth activity decreased, the traps were checked every other week. Traps were placed at the warehouse from March 1992 to March 1997.

From October 1995 to July 1996, we placed three wing traps baited with virgin female navel orangeworm, *Amyelois transitella* (Walker), in the dock area. Each week, five female navel orangeworm pupae from laboratory cultures were placed in cages made by heat-sealing the edges of nylon window screen to form pyramidal bags (4 by 4 cm) (Curtis and Clark 1984). We selected pupae of various ages to ensure a continuous supply of calling females throughout the week. The cages were hung on wire clips placed under the tops of the traps. Traps were checked and replaced each week.

Flight Trap Monitoring of Parasitoids. To monitor adult parasitoid activity, we used yellow sticky aphid boards (Consep) as flight traps. Eight of these traps were placed on or around the dock, alongside the fig mass, and one was placed within the warehouse. The flight traps were collected each week (every other week during the winter) from March 1992 to March 1997. Any insect parasitoids caught on the traps were identified to the lowest possible taxon. The average number of parasitoids per trap per day was calculated for thirteen 4-wk intervals for each year and analyzed with the General Linear Models analysis of variance (ANOVA) procedure (SAS Institute 1989). Where ANOVA showed significant differences between sampling intervals, means were separated using least significant difference (LSD) (SAS Institute 1989).

Early in the study, we also placed flight traps at different heights directly above the fig mass, beginning on 24 April 1992 and ending on 10 July 1992. We hung four flight traps 0.5 m apart from each of two pieces (2.4 m by 2.5 cm by 5 cm) of pine board. The bottoms of the boards were placed in the fig mass so that the tops of the traps were 0.5, 1.0, 1.5, and 2.0 m above the surface of the figs. The two boards were set ≈10 m apart. The traps were replaced each week, and the number of parasitoids was determined. Where appropriate to normalize the variances, square-root transformations were performed on the number of total parasitoids recovered from the traps before further analysis. ANOVA followed by LSD mean separation was done with SPSS Base 8.0 (SPSS 1998).

Sentinel Traps for Parasitoids. We used sentinel traps, baited with host insects, to obtain parasitoids for laboratory culture. Host insects were obtained from laboratory colonies maintained by the insect rearing facility of the Horticultural Crop Research Laboratory, Fresno, CA, Traps were made from plastic deli containers (500 ml).

To collect pyralid larval parasitoids, 50 ml of rearing medium with second to fifth instars of Indianmeal moth was placed in the containers. Larvae were prevented from escaping from the trap by removing the bottom of another deli container, applying tangle trap (Mapco Products, Emeryville, CA) to the inside surface, and nesting it within the trap. Traps containing fourth and fifth instars were placed at the warehouse from March 1992 to March 1997. Traps baited with younger larvae (second and third instars) were placed at the warehouse from July 1994 to March 1997.

To collect pyralid pupal parasitoids, corrugated cardboard strips containing Indianmeal moth pupae were placed in plastic deli containers. Traps with pupae were first placed at the warehouse in June 1995 and were continued to March 1997. Sentinel traps for beetle parasitoids contained ≈50 ml of rearing medium with various stages of either *Oryzaephilus* species, *O. surinamensis,* or *O. mercator* (Flauvel); red flour beetle, *Tribolium castaneum* (Herbst); or cigarette beetle, *Lasioderma serricorne* (F.). Sentinel traps for beetle parasitoids were placed at the warehouse from June 1995 to March 1997.

All sentinal traps were monitored on the same schedule as flight and pheromone traps. After removal from the warehouse, sentinel traps were closed with plastic lids and held in the laboratory for emergence of adult parasitoids. The percentage of sample dates in which parasitoids were recovered from sentinel traps was calculated for thirteen 4-wk intervals for each year. Data were analyzed using the GLM ANOVA procedure (SAS Institute 1989).

Table 1. Insect taxa recovered from a culled-fig warehouse on flight traps, excluding parasitoids

Order	Family	Species	Category
Blattodea	Blattidae	*Periplaneta americana*	Scavenger
Hemiptera	Anthocoridae	*Xylocoris* Dufor	Predator
Lepidoptera	Pyralidae	*P. interpunctella*	Dried-fruit feeder
		C. figulilella	Dried-fruit feeder
		C. cautella	Dried-fruit feeder
		E. elutella	Dried-fruit feeder
		E. kuehniella	Dried-fruit feeder
		A. transitella	Dried-fruit feeder
		P. farinalis	Dried-fruit feeder
Coleoptera	Silvanidae	*O. mercator*	Dried-fruit feeder
	Laemophloeidae	*Cryptolestes*	Dried-fruit feeder
	Tenebrionidae	*T. castaneum*	Dried-fruit feeder
		Blapstinus Sturm	Scavenger
	Nitidulidae	*C. hemipterus*	Dried-fruit feeder
	Anobiidae	*L. serricorne*	Dried-fruit feeder
	Dermestidae	Various	Dried-fruit feeder/scavenger
Diptera	Drosophilidae	*Drosophila* Fallén	Dried-fruit feeder
	Stratiomyidae	*Hermeticia illucens* (L.)	Dried-fruit feeder
	Muscidae	Various	Filth feeder
Hymenoptera	Formicidae	Various	Predator, scavenger

Results

Table 1 lists the insect taxa collected from the fig mass, flight traps, or pheromone traps, excluding hymenopterous parasitoids. Indianmeal moth pheromone traps recovered all five pyralid species known to be attracted to the commercial lure—Indianmeal moth, raisin moth, almond moth, tobacco moth, and the Mediterranean flour moth. In addition, traps baited with navel orangeworm females caught both males of this species and of the mealmoth, *Pyralis farinalis* L.

Several common dried-fruit beetles were recovered from the warehouse. Those most often encountered were merchant grain beetle, (*O. mercator*); driedfruit beetle; cigarette beetle; red flour beetle; various dermestids; and species in the genus *Cryptolestes* Ganglbauer. Other common inhabitants of the warehouse included American cockroaches, *Periplaneta americana* (L.); species in the genus *Drosophila* Fallén; muscids; ants; and predatory anthocorids in the genus *Xylocoris* Dufor.

The mean, maximum, and minimum weekly temperatures; monthly fig tonnage; and average monthly pheromone trap catches of pyralid moths are shown in Fig. 1. Indianmeal moths made up the bulk (94.4%) of the moths recovered, followed by raisin moth (5.5%), and Mediterranean flour moth (0.1%). Only six almond moths and five tobacco moths were recovered. Because of the large number of moths caught (>150,000 over the course of the study), not all the moths were positively identified by examination of male genitalia. Because of the similarity between the *Cadra* species and *E. elutella*, it is possible that some almond moths and tobacco moths were misidentified as raisin moths.

We found two peaks to occur in Indianmeal moth numbers; the first in the spring, corresponding to emergence of moths from diapause, and the second after new, infested figs arrived at the warehouse in late summer. Indianmeal moth trap catches fell to zero during the winter, and also dropped in late summer. The lack of winter activity was probably caused by the Indianmeal moth population entering diapause. The decrease in moth numbers during the summer was associated both with high temperatures and with low fig volumes. Peak numbers of Indianmeal moths seemed to decline over the last 3 yr of the study. Raisin moth activity was limited to a short period in the fall and was associated with the arrival of new figs.

During the period that navel orangeworm presence was monitored with traps baited with virgin females (October 1995 to July 1996), 172 males were recovered. Of these, 85% were caught before the end of November 1995. The remainder was caught between May and July 1996 following late deliveries of new figs in March and April. This recovery pattern demonstrates the presence of navel orangeworm at the warehouse and suggests that they are brought in with new figs.

Table 2 gives the parasitoid taxa recovered from flight traps. The parasitoid family best represented was Bethylidae, with at least seven species being recovered. Of these, only *Cephalonomia tarsalis* (Ashmead) and *C. gallicola* Ashmead were successfully cultured in our laboratory on *Oryzaephilus* and cigarette beetle larvae, respectively. A single chalcid, an unidescribed species of *Psilochalcis* Keifer, was found and was successfully cultured on pyralid pupae. The encyrtid species *Cerchysiella utilis* Noyes was detected and is the first such record from the continental United States. A single pteromalid species, *Anisopteromalus calandrae* (Howard), was found and was successfully cultured on cigarette beetle pupae. Two ichneumonids were recovered—*Venturia canescens* (Gravenhorst) and *Mesostenus gracilis* (Cresson); both were succesfully cultured on pyralid larvae and pupae, respectively. Because *V. canescens* reproduces parthenogenically almost exclusively (Brower et al. 1995), no males were found. The braconid *Habrobracon hebetor* (Say) was another common parasitoid found on the flight traps

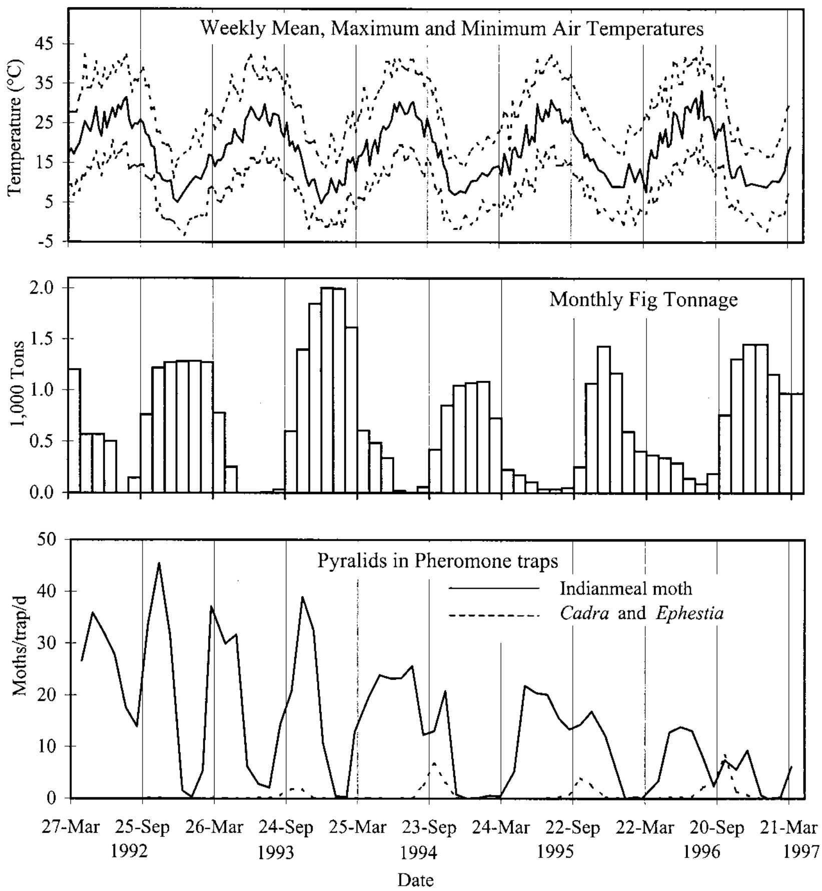

Fig. 1. Mean, maximum, and minimum temperatures, monthly fig volume, and numbers of moths collected at pheromone traps at the culled-fig warehouse.

and was successfully cultured on pyralid larvae. We have submitted voucher specimens of *H. hebetor*, *V. canescens*, *M. gracilis*, *Psilochalcis* n. sp., *C. tarsalis*, *C. gallicola*, *Laelius centratus* (Say), and *A. calandrae* to the USDA-ARS Systematic Entomology Laboratory, Beltsville, MD. Voucher specimens of *C. utilis* were deposited in The Natural History Museum, London.

Table 2. Parasitoid taxa recovered from a culled-fig warehouse in flight traps

Family	Species	Assumed Host
Chalcididae	*Psilochalcis* new sp.[a,b]	Pyralid pupae
Encyrtidae	*C. utilis*[c]	Nitidulid larvae
Pteromalidae	*A. calandrae*[b]	Beetle larvae, pupae
Bethylidae	*C. tarsalis*[b]	*Oryzaephilus* larvae
	C. gallicola[b]	Beetle larvae
	C. waterstoni	Beetle larvae
	Goniozus	Pyralid larvae
	Plastonoxus westwoodi (Keiffer)	Anobiid larvae
	L. centratus	Dermestid larvae
	H. sylvanidis Bréthes	Beetle larvae
Braconidae	*H. hebetor*[b]	Pyralid larvae
Ichneumonidae	*V. canescens*[b]	Pyralid larvae
	M. gracilis[b]	Pyralid pupae

[a] New species and host record.
[b] Species from which laboratory cultures have been established.
[c] First record from California.

Table 3 shows the effect of flight trap height on parasitoid recovery. Trap height had a significant effect on the recovery of *H. hebetor* ($F = 11.0$; df = 3, 87; $P < 0.001$) and the bethylids ($F = 14.2$; df = 3, 87; $P < 0.001$), with the highest number of parasitoids captured on the lowest trap. Male *H. hebetor* were more strongly affected than females; 40% of the females collected were caught on the lowest traps compared with 53% of the males. Nearly twice as many male (65%) as female (35%) *H. hebetor* were captured on the traps. Recovery of *V. canescens* was not significantly affected by trap height ($F = 1.1$; df = 3, 87; $P = 0.369$), but this result may be in part caused by the low numbers of *V. canescens* recovered by the traps. In total, 184 *V. canescens* were collected on the traps compared with 2,075 *H. hebetor* and 6,429 bethylids.

Observations made shortly after new figs were brought to the warehouse indicated that *H. hebetor* was among the predominant mortality factors acting on the pyralid populations. Examination of fig bins and

Table 3. Effect of height of flight traps over fig mass on parasitoid recovery

Trap height, m[a]	*H. hebetor* ♀♀	*H. hebetor* ♂♂	*H. hebetor* Total	Bethylidae	*V. canescens*
2.0	5.0 ± 1.2a	7.7 ± 1.7a	12.7 ± 2.8a	33.9 ± 5.8a	2.0 ± 0.7
1.5	6.8 ± 1.3a	8.5 ± 1.8a	15.4 ± 2.8a	48.2 ± 7.2a	1.8 ± 0.4
1.0	8.1 ± 1.4ab	12.4 ± 1.9a	20.5 ± 3.1a	81.8 ± 10.0b	1.7 ± 0.3
0.5	13.4 ± 2.4b	32.3 ± 21.8b	45.7 ± 7.2b	128.3 ± 18.2c	2.9 ± 0.3

Values are mean number of parasitoids recovered per trap per day. Means (± SE) within columns followed by the same letter are not significantly different ($P > 0.05$, LSD; data for *H. hebetor* and for bethylids square-root transformed).
[a] Height given is distance from top of fig mass to top of trap; traps are 0.2 m long.

the surrounding floors yielded numerous pyralid larvae that had been stung and paralyzed by *H. hebetor. H. hebetor* also was one of the most common parasitoids found on flight traps, with 17,041 recovered during 5 yr of sampling.

Analysis of the number of *H. hebetor* recovered from flight traps across the five sampling years (Table 4) showed a significant difference for sampling interval ($F = 2.6$; df = 12, 52; $P = 0.008$). Two peaks in trap numbers can be seen, one occurring in the 25 March–23 April interval and the second in the 5 November–3 December interval. These peaks in flight trap numbers occurred nearly every year of the study and also are reflected in the percentage of sentinel traps containing *H. hebetor* (Fig. 2). The peaks roughly correspond to the peak pheromone trap numbers for Indianmeal moth (Fig. 1). Trap recovery of *H. hebetor* was lowest in 16 July–13 August and declined again during the winter (Table 4). Although *H. hebetor* numbers on flight traps were low during the winter, seldom were there winter sampling dates when no *H. hebetor* were recovered. Observations made during the winter indicated that *H. hebetor* was active on warm winter days and was capable of both paralyzing and parasitizing host larvae.

Habrobracon hebetor was found significantly more often than *V. canescens* ($F = 17.4$; df = 1, 128; $P < 0.001$) in sentinel traps baited with older host larvae (fourth and fifth instars), over the entire sampling period (Table 5). *H. hebetor* was recovered significantly less often from sentinel traps containing younger larvae (second and third instars) than from traps containing older larvae ($F = 7.8$; df = 1, 68; $P = 0.007$). In contrast, *V. canescens* was recovered at the same frequency from traps containing either age of host larvae ($F = 0.42$; df = 1, 68; $P = 0.52$). *H. hebetor* and *V. canescens* were recovered at the same frequency from traps containing younger host larvae ($F = 1.5$; df = 1, 68; $P = 0.22$).

We found *V. canescens* in flight traps in much lower numbers (4,615 over 5 yr) than *H. hebetor.* As with *H. hebetor,* analysis of the number of *V. canescens* recovered from flight traps across the five sampling years (Table 4) showed a significant difference for sampling interval ($F = 5.3$; df = 12, 52; $P < 0.001$). Seasonal activity of *V. canescens* was similar to *H. hebetor,* with one peak in the spring and one in the winter (Table 4; Fig. 3), but the spring peak of *V. canescens* activity was ≈8 wk later than that of *H. hebetor. M. gracilis* was recovered at even lower levels than *V. canescens;* only 338 *M. gracilis* were found in 5 yr of sampling. *M. gracilis* was recovered only from sentinel traps containing pyralid pupae once out of 101 sampling dates. Again, most *M. gracilis* were recovered from flight traps in the spring and after new figs were received in the fall (Fig. 3).

The single largest group of parasitoids recovered from flight traps was the bethylids, with a total of 28,216 collected over the 5-yr sampling period. Analysis of the number of bethylids recovered from flight traps across the five sampling years (Table 4) showed a significant difference for sampling interval ($F = 2.3$; df = 12, 52; $P = 0.02$). Bethylids were most numerous during warm weather and their numbers declined as

Table 4. Seasonal incidence of parasitoids in flight traps

Sampling interval	*H. hebetor*	Bethylidae	*V. canescens*
25 March–23 April	3.80 ± 1.85a	1.22 ± 0.63cde	0.10 ± 0.04c
23 April–21 May	2.37 ± 1.24ab	2.54 ± 0.42abcd	0.49 ± 0.18ab
21 May–18 June	0.90 ± 0.37bcd	3.81 ± 1.95a	0.67 ± 0.22a
18 June–16 July	0.26 ± 0.10dc	3.67 ± 1.11ab	0.25 ± 0.09bc
16 July–13 Aug.	0.07 ± 0.02d	2.78 ± 0.27abc	0.03 ± 0.01c
13 Aug.–10 Sept.	0.13 ± 0.07dc	2.74 ± 0.48abc	0.04 ± 0.01c
10 Sept.–8 Oct.	0.25 ± 0.06dc	2.20 ± 0.63abcde	0.21 ± 0.06bc
8 Oct.–5 Nov.	1.28 ± 0.34bcd	1.33 ± 0.44bcde	0.77 ± 0.21a
5 Nov.–3 Dec.	2.07 ± 0.80abc	0.71 ± 0.38cde	0.67 ± 0.23a
3 Dec.–31 Dec.	0.82 ± 0.36bcd	0.31 ± 0.16de	0.17 ± 0.08bc
31 Dec.–28 Jan.	0.15 ± 0.04dc	0.02 ± 0.01e	0.02 ± 0.01c
28 Jan.–25 Feb.	0.18 ± 0.08dc	0.21 ± 0.09de	0.01 ± 0.00c
25 Feb.–25 March	0.78 ± 0.48bcd	1.62 ± 0.88abcde	0.02 ± 0.01c

Values are mean number of parasitoids recovered per trap per day. Means (± SE) within columns followed by the same letter are not significantly different ($P > 0.05$, LSD).

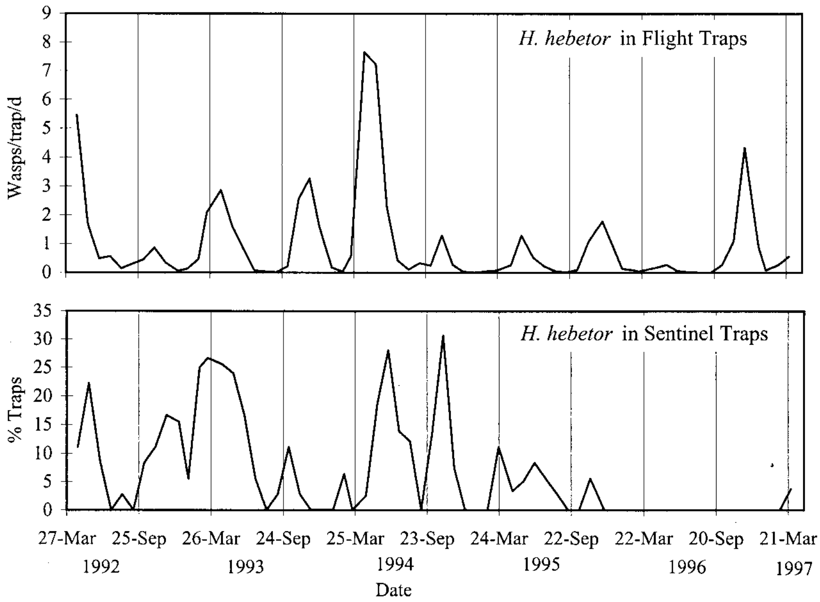

Fig. 2. Average monthly number of *H. hebetor* collected on flight traps and recovered from sentinel traps at the culled-fig warehouse.

temperatures dropped (Table 4; Fig. 3). Identification of bethylids to genus was possible only after April 1996. The three most common bethylid genera captured on flight traps were *Goniozus, Laelius,* and *Cephalonomia.* Species determinations were not obtained for *Goniozus.* The *Laelius* species was determined to be *L. centratus.* The most common *Cephalonomia* species was *C. tarsalis,* but *C. waterstoni* (Gahan) and *C. gallicola* also were captured. The occurrence of these three genera during the last year of sampling is given in Fig. 4. *Goniozus,* which are primarily parasitoids of lepidopteran larvae (Gordh and Moczar 1990, Gordh and Hartman 1991), were most prevalent in the spring, whereas *Laelius* and *Cephalonomia,* which are both parasitoids of beetles (Gordh and Hartman 1991), were more active during the summer. *Goniozus* was recovered twice from sentinel traps containing second and third instars of pyralids. *C. tarsalis* was recovered from sentinel traps containing *Oryzaephilus* larvae on six of 70 sampling dates. *C. gallicola* was recovered once from sentinel traps with cigarette beetles. Neither *C. waterstoni* nor *L. centratus* were recovered from sentinel traps.

Table 5. Incidence of parasitoids in sentinel traps baited with Indianmeal moth larvae

Host age (sampling period)	*n*	*H. hebetor*	*V. canescens*
Older larvae (1992–1996)	65	29.6 ± 3.9	10.5 ± 2.3
Older larvae (1994–1996)	35	17.6 ± 4.7	5.9 ± 2.4
Younger larvae (1994–1996)	35	3.6 ± 1.8	8.9 ± 3.9

Values are mean (± SE) percentage of incidence of parasitoid recovery from sentinel traps per 4-wk sampling interval.

The number of *Psilochalcis* recovered per flight trap per day is shown in Fig. 5. When sampling first began in 1992, chalcids were only occasionally seen in flight traps, and, because they are not generally known from stored product insects, were ignored. By 1995, however, we noticed that flight traps periodically had large numbers of chalcids. After the chalcids were identified as *Psilochalcis,* we began to record their numbers. From late April 1995 to the end of the study, 4,824 *Psilochalcis* were recorded. Of these, 3,086 (64%) were recorded in the first year. *Psilochalcis* was recovered from flight traps beginning in the spring but numbers peaked in late summer and early fall. In 1995, the increase in *Psilochalcis* seemed to preceed the arrival of new figs. *Psilochalcis* was recovered from sentinel traps containing pyralid pupae on two of 101 sample dates.

Cerchysiella utilis was first noticed in flight traps in July 1995. We found large numbers of *C. utilis* in mid-November 1995 (Fig. 5), but observed no similar peaks during the remainder of the study. In total, 2,337 *C. utilis* were recovered during 1995 and 1996; 1,893 (81%) of these individuals were collected in 1995. *A. calandrae* was periodically recovered from flight traps throughout the study (Fig. 5), but numbers were not recorded until late in 1995. *A. calandrae* were first collected in the spring, but the greatest number of *A. calandrae* were recovered in June, when the volume of figs at the warehouse was low. *A. calandrae* was collected from sentinel traps containing cigarette beetles on three of 70 sampling dates.

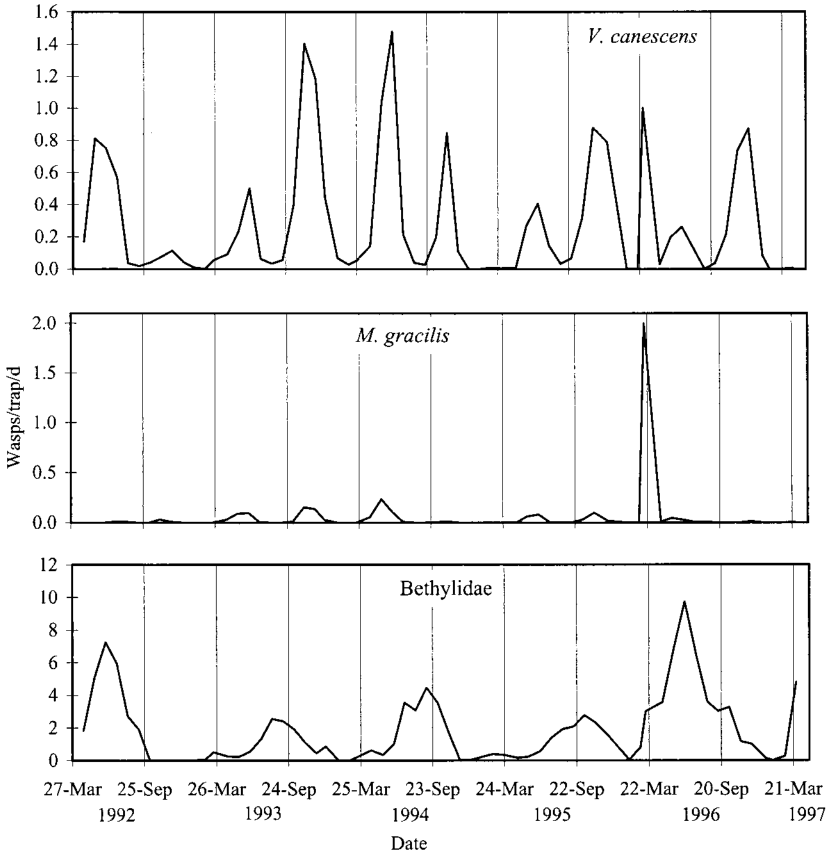

Fig. 3. Average monthly number of *V. canescens*, *M. gracilis*, and Bethylidae collected on flight traps at the culled-fig warehouse.

Discussion

Colored sticky traps have been used to monitor a number of parasitoid species (Maier 1992, Brodeur and McNeil 1994). A wide range of phytophagous insects is attracted to yellow traps (Prokopy and Owens 1983), and several studies have found yellow traps to be the most attractive for various hymenopterous parasitoids (Moreno et al. 1984, Ridgway and Mahr 1986). However, McClain et al. (1990) found that some aphelinid species responded more strongly to trap colors other than yellow. For our traps, yellow was selected because of its general utility and the availability of ready-made traps. Also, because of the high parasitoid densities found at the fig warehouse, maximizing the efficacy of the traps seemed unnecessary. Because the relative effect of trap color on response of the different parasitoid species collected in our study is unknown, care must be taken when making comparisons between species.

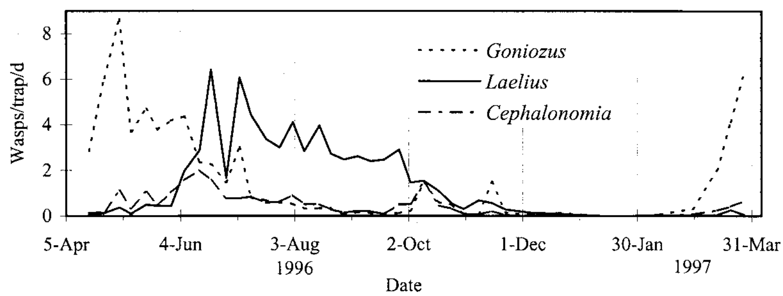

Fig. 4. Average weekly number of *Goniozus*, *Laelius*, and *Cephalonomia* collected on flight traps at the culled-fig warehouse.

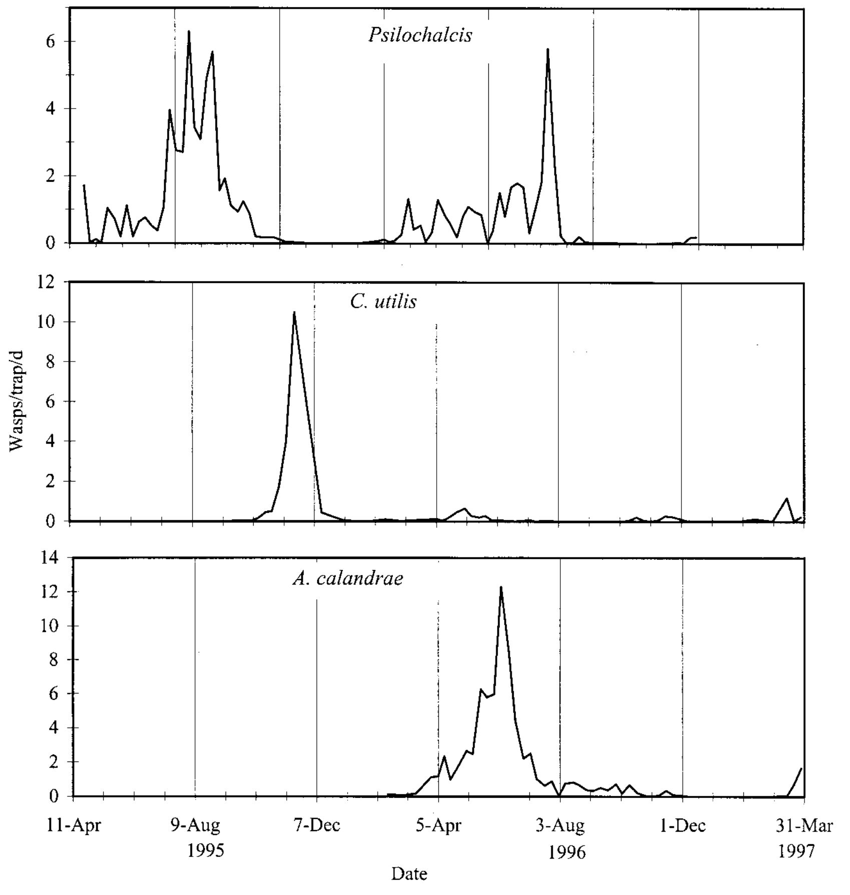

Fig. 5. Average weekly number of *Psilochalcis, C. utilis* and *A. calandrae* collected on flight traps at the culled-fig warehouse.

Our traps placed directly over the fig mass collected large numbers of parasitoids and other dried fruit insects over a relatively short period of time. Because of concerns that the large numbers of insects collected might decrease the relative efficiency of the traps, and because these traps were more likely to be destroyed as figs were removed from the mass, we decided that continued trapping above the fig mass was unnecessary. We found that, for *H. hebetor* and the bethylids, parasitoid density decreased as height above the fig mass increased. Because these parasitoids would probably be searching the fig mass for suitable hosts or mates, this observation is to be expected. We found more male *H. hebetor* in traps placed directly above the fig mass. This result can be explained by the observations of Antolin and Strand (1992), in which *H. hebetor* males were more likely to be found on the surface of stored corn, whereas females were more often found beneath the surface. Recovery of *V. canescens* did not seem to be strongly affected by trap height, which may be because of the larger size and stronger flight of this parasitoid or the lower number of parasitoids collected.

At the culled-fig warehouse, we found at least five species that were parasitoids of pyralid larvae or pupae. Three of these species, *H. hebetor, V. canescens,* and *M. gracilis,* have been recovered from sentinel traps placed in central California fig orchards, raisin grape vineyards, and tree fruit orchards (J.A.J., unpublished data). Raisin moth is a common pest of California raisin vineyards and fig orchards, where it attacks drying fruit (Simmons and Nelson 1975), and also may develop in tree-fruit orchards on dropped plums, peaches, apricots, and nectarines (Donohoe et al. 1949). Because *H. hebetor, V. canescens,* and *M. gracilis* have been recorded from raisin moths in central California (Donohoe et al. 1949), we assume that parasites recovered from sentinel traps in orchards and vineyards are from populations normally parasitizing raisin moths. Substandard figs brought to the culled fig warehouse are often infested with raisin moths, and the recovery of this species in pheromone traps shortly after receipt of new figs confirms this. It is likely that the increased activity noted in the fall for these three parasitoid species is caused partly by the presence of parasitized raisin moths in newly received figs, as well as to resident parasitoid populations responding to the increase in hosts.

Venturia canescens and *H. hebetor* are direct competitors, because both parasitize late-instar pyralids.

Press et al. (1977) noted that *V. canescens* numbers were suppressed by the presence of *H. hebetor*, but that *H. hebetor* was unaffected by *V. canescens.* They suggested that this finding, along with the greater reproductive capability of *H. hebetor*, would result in eventual elimination of *V. canescens* when these two species are introduced into warehouses to control pyralids. Our study shows that populations of both species coexist at the culled-fig warehouse, although *H. hebetor* seemed to be more prevalent. Although this coexistance may be explained by the abundance of host larvae and the periodic addition of parasitoids with new figs, it is also possible that these species exploit different portions of the host population. Harvey et al. (1994) found that *V. canescens* successfully parasitized a range of host sizes. Hagstrum and Smittle (1978) noted that *H. hebetor* attacked mature, wandering larvae 10 times more often than they attacked concealed larvae, and they suggested that *H. hebetor* would therefore rarely parasitize the younger larvae hidden within the product. In the current study, we recovered *H. hebetor* more often from sentinel traps containing older larvae (17.6%) than from traps with younger larvae (3.5%), whereas *V. canescens* was recovered at about the same rate (5.9 and 8.9%, respectively). These results indicate that *V. canescens* may be able to coexist with *H. hebetor* by exploiting a greater range of host sizes, and that periodic innundative release of both parasitoid species may result in better control of storage pyralids.

The relative success of *H. hebetor* and *V. canescens* also may be affected by the presence in the fig mass of red flour beetle, which is known to prey on immature stages of other stored product insects. Press et al. (1986) showed that the number of *H. hebetor* was reduced when red flour beetles were present but that *V. canescens* numbers were unaffected. Presumably, *H. hebetor* are more vulnerable to predation as external parasites of paralyzed hosts than *V. canescens*, which develops internally in active hosts. *H. hebetor* also avoids areas containing red flour beetle (Press 1988), which may give additional advantage to *V. canescens.*

Habrobracon hebetor adults were active for most of the winter. Indianmeal moth and raisin moth populations in central California overwinter as diapausing fifth instars. Donohoe et al. (1949) noted that *H. hebetor* was capable of stinging and paralyzing raisin moth larvae on warm winter days and also was capable of parasitizing host larvae within cocoons. That *H. hebetor* adults are able to survive California winters, and even parasitize host larvae on warm days, suggests that winter release of these parasitoids into dried fruit and nut storages may be a useful control strategy for Indianmeal moth.

We recovered large numbers of *Goniozus* on flight traps, particularly in the spring. *Goniozus* is a large, cosmopolitan genus with ≈150 species worldwide (Gordh and Moczar 1990). Because many *Goniozus* species are considered to be important biological control agents, this genus is one of the most studied of the Bethylidae. Gordh and Hartman (1991) lists *Goniozus* species as being associated with insect pests of stored products. Although *Goniozus* are nearly exclusively parasitoids of lepidopterous larvae, they are not host specific; the host range for most species includes several families of Lepidoptera (Gordh and Moczar 1990).

At least three species of *Goniozus* are listed as parasitizing navel orangeworm larvae—*G. breviceps*, *G. emigratus*, and *G. legneri* (Gordh and Moczar 1990). Navel orangeworm is a common pest of figs (Simmons and Nelson 1975). Primarily a field pest, navel orangeworm does not reproduce well in storage environments. We collected numerous adults in traps baited with virgin females when new figs were being received at the warehouse, usually in late summer and early fall. Based on our trapping results, we suggest that navel orangeworm larvae are brought to the warehouse in new figs, but emerging adults do not reinfest stored figs. We first speculated that *Goniozus* found at the warehouse was associated with navel orangeworm, but we did not detect an increase in *Goniozus* activity that corresponded with receipt of new figs. The *Goniozus* present at the culled-fig warehouse lacks an aerolet in the forewing, which precludes it being any of the three species associated with navel orangeworm (Evans 1978, Gordh 1982). *Goniozus* also must compete with *H. hebetor* and *V. canescens* for suitable hosts. Like *H. hebetor*, *Goniozus* develops externally on paralyzed hosts, and may have the same competive advantages and disadvantages over *V. canescens.* We recovered *Goniozus* only twice from sentinel traps, both times from traps containing younger larvae. If this parasitoid prefers younger larvae, it may not be directly competing with *H. hebetor.*

Chalcididae are not well known as parasitoids of stored product insects; Gordh and Hartman (1991) list two species of *Antrocephalus* as parasites of the rice moth. *Psilochalcis* has not previously been recovered from stored product pyralids. Few host records for *Psilochalcis* are known; most are small Lepidoptera, including Pyralidae and Gelechiidae (Grissell and Schauff 1981, Delvare and Bouček 1992). Delvare and Bouček (1992) report that fewer than 20 species of *Psilochalcis* are known from the Western Hemisphere, including four species originally described in the genus *Invreia* (Grissell and Schauff 1981). The chalcid found at the culled-fig warehouse has been identified as an undescribed species of *Psilochalcis.* Preliminary laboratory studies on the biology of this chalcid indicate that it is capable of parasitizing the pupae of several stored product pyralids, including Indianmeal moth, raisin moth, almond moth, tobacco moth, and navel orangeworm (J.A.J., unpublished data).

We recovered the highest number of *Psilochalcis* from flight traps during the summer, when the other pyralid parasitoids were far less active and before new figs were brought into the warehouse. It is unclear whether the increase in *Psilochalcis* is caused by an increase in the population or by an increase in adult searching activity as the supply of hosts decreases. Many more *Psilochalcis* (4,824 over 23 mo) were collected than *Mesostenus gracilis* (338 over 5 yr), the only other parasitoid of pyralid pupae found at the warehouse. Our observations on laboratory-reared *M. gracilis* showed that larvae develop within host cocoons, but externally to host pupae, and may be more vulnerable to predation than *Psilochalcis.* Because *Psilochalcis* does not directly compete with *H. hebetor* and is active during the summer when *H. hebetor* activity declines, it may be a useful component in biologically based control programs.

Of the several beetle parasitoids recovered from the culled-fig warehouse, those most numerous were *L. centratus, Cephalonomia* spp., *A. calandrae,* and *C. utilis.* Of most interest is the discovery of *C. utilis,* a parasitoid described originally in the genus *Zeteticontus.* First found in Kenya and Israel, this species was released in Hawaii for control of nitidulid beetles (Noyes 1982, Funasaki et al. 1988). Biological studies of this species were done by Gerling and Ben-Mordechai (1981), Blumberg et al. (1984), and Werner and Williams (1985). Noyes (1982) notes plans to release *C. utilis* against *Carpophilus* in Ohio, but we were unable to find any records of such a release. There were also no records of permits for release of this species in California (Barbara Hass, California Department of Food and Agriculture, personal communication). A survey of natural enemies of *Carpophilus* spp. in central California conducted in 1974 found no larval parasitoids (Ehler and Smilanick 1975). We assume that *C. utilis* was inadvertently introduced into California with produce infested with parasitized *Carpophilus* larvae. Unfortunately, we have been unable to obtain a laboratory culture of this species.

Insect management programs that rely solely on natural enemies are unlikely to provide the degree of control suitable for postharvest dried fruits and nuts. However, periodic innundative release of parasitoids to reduce pest populations in bulk product or to clean up empty storage facilities may find a place along with other management practices, such as low temperature storage or modified atmospheres. Our study suggests that, because the parasitoids found at the culled-fig warehouse are capable of partitioning the available host population, at least for typical dried fruit and nut storage durations, the periodic release of a complex of parasitoid species may exert greater control. The relatively mild winters of central California also allow the possibility of winter release of *H. hebetor* against diapausing pyralid populations.

Acknowledgments

We thank Shirley May, Annie Lopez, and Karen Crozier (Horticultural Crops Research Laboratory, USDA–ARS); Steve Klamm, manager of the substandard fig warehouse; and the California Fig Advisory Board for their assistance in this study. We acknowledge Eric Grissell (Systematic Entomology Laboratory, USDA–ARS , Beltsville, MD) for identification of *Psilochalcis* as an undescribed species, Johns Noyes (The Natural History Museum, London) for identification of *C. utilis,* and Barbara Hass (California Department of Food and Agriculture) for searching the natural enemy release record. We also thank Patrick V. Vail (Horticultural Crops Research Laboratory, USDA–ARS), Richard T. Arbogast (Center for Medical, Agricultural, and Veterinary Entomology, USDA-ARS), and Michael Antolin (Colorado State University) for reviewing the manuscript.

References Cited

Antolin, M. F., and M. R. Strand. 1992. Mating system of *Bracon hebetor* (Hymenoptera: Braconidae). Ecol. Entomol. 17: 1–7.

Blumberg, D., M. Demeter, M. Kehat, and R. N. Williams. 1984. Biological studies of *Zeteticonthus utilis* (Hymenoptera: Encyrtidae), a parasite of *Carpophilus* spp. (Coleoptera: Nitidulidae). Ann. Entomol. Soc. Am. 77: 130–133.

Brodeur, J., and J. N. McNeil. 1994. Seasonal ecology of *Aphidius nigripes* (Hymenoptera: Aphidiidae), a parasitoid of *Macrosiphum euphorbiae* (Homoptera: Aphididae). Environ. Entomol. 23: 292–298.

Brower, J. H., L. Smith, P. V. Vail, and P. W. Flinn. 1995. Biological control, pp. 223–286. *In* B. Subramanyam and D. W. Hagstrum [eds.], Integrated management of insects in stored products. Marcel Dekker, New York.

Curtis, C. E., and J. D. Clark. 1984. Pheromone application and monitoring equipment used in field studies of the navel orangeworm (Lepidoptera: Pyralidae). J. Econ. Entomol. 77: 1057–1061.

Delvare, G., and Z. Bouček. 1992. On the New World Chalcididae (Hymenoptera). Mem. Am. Entomol. Inst. (Gainesville) 53: 1–466.

Donohoe, H. C., P. Simmons, D. F. Barnes, G. H. Kaloostian, and C. K. Fisher. 1949. Biology of the raisin moth. (U.S. Dep. Agric. Tech. Bull. 994.

Ehler, L. E., and J. M. Smilanick. 1975. Potential for biological control of dried fruit beetle and confused sap beetle in California. Proc. Calif. Fig Inst.: 30–38.

Evans, H. E. 1978. The Bethylidae of America north of Mexico. Mem. Am. Entomol. Inst. 27: 1–332.

Funasaki, G. Y., L. M. Nakahara, and B. P. Kumashiro. 1988. Introductions for biological control in Hawaii; 1985 and 1986. Proc. Hawaii. Entomol. Soc. 28: 101–104.

Gerling, D., and Y. Ben-Mordechai. 1981. Biological observations with *Zeteticontus* sp. (Hymenoptera: Encyrtidae) a parasite of *Carpophilus hemipterus* (L.) (Coleoptera: Nitidulidae). Proc. Hawaii. Entomol. Soc. 23: 351–354.

Gordh, G. 1982. A new species of *Goniozus* (Hymenoptera: Bethylidae) imported into California for the biological control of the navel orangeworm (Lepidoptera: Pyralidae). Entomol. News 93: 136–138.

Gordh, G., and H. Hartman. 1991. Hymenopterous parasites of stored-food insect pests, pp. 217–227. *In* J. R. Gorham [ed.], Ecology and management of food-industry pests. FDA technical bulletin 4. Association of Official Analytical Chemists, Arlington, VA.

Gordh, G., and L. Moczar. 1990. A world catalog of the Bethylidae (Hymenoptera: Aculeata). Mem. Am. Entomol. Inst. 46: 1–362.

Grissell, E. E., and M. E. Schauff. 1981. New Nearctic *Invreia* (Hymenoptera: Chalcididae) from lepidopterous pests of peanut. Proc. Entomol. Soc. Wash. 83: 1–12.

Hagstrum, D. W., and B. J. Smittle. 1978. Host utilization by *Bracon hebetor.* Environ. Entomol. 7: 596–600.

Harvey, J. A., I. F. Harvey, and D. J. Thompson. 1994. Flexible larval growth allows use of a range of host sizes by a parastioid wasp. Ecology 75: 1420–1428.

Maier, C. T. 1992. Seasonal development, flight activity, and density of *Sympiesis marylandensis* (Hymenoptera: Eulophidae), a parasitoid of leaf-mine *Phyllonorycter* spp.

(Lepidoptera: Gracillariidae), in Connecticut apple orchards and forests. Environ. Entomol. 21: 164–172.

McClain, D. C., G. C. Rock, and J. B. Woolley. 1990. Influence of trap color and San Jose scale (Homoptera: Diaspididae) pheromone on sticky trap catches of 10 aphelinid parasitoids (Hymenoptera). Environ. Entomol. 19: 926–931.

Moreno, D. S., W. A. Gregory, and L. K. Tanigoshi. 1984. Flight response of *Aphytis melinus* (Hymenoptera: Aphelinidae) and *Scirtothrips citri* (Thysanoptera: Thripidae) to trap color, size and shape. Environ. Entomol. 13: 935–940.

Noyes, J. S. 1982. A new species of *Zeteticontus* Silvestri (Hymenoptera: Encyrtidae) from Israel and Kenya, a parasite of *Carpophilus hemipterus* (L.) (Coleoptera: Nitidulidae). Bull. Entomol. Res. 72: 457–460.

Press, J. W. 1988. Avoidance of the red flour beetle, *Tribolium castaneum* (Coleoptera: Tenebrionidae), by *Bracon hebetor* Say (Hymenoptera: Braconidae) J. Kans. Entomol. Soc. 61: 228–230.

Press, J. W., B. R. Flaherty, and R. T. Arbogast. 1977. Interactions among *Nemeritis canescens* (Hymenoptera: Ichneumonidae), *Bracon hebetor* (Hymenoptera: Braconidae), and *Ephestia cautella* (Lepidoptera: Pyralidae). J. Kans. Entomol. Soc. 50: 259–262.

Press, J. W., L. D. Cline, and B. R. Flaherty. 1986. Impact of the red flour beetle, *Tribolium castaneum* (Herbst), on suppression of the almond moth, *Cadra cautella* (Walker), by the parasitic wasps, *Bracon hebetor* Say and *Venturia canescens* (Gravenhorst). J. Entomol. Sci. 21: 271–275.

Prokopy, R. J., and E. D. Owens. 1983. Visual detection of plants by herbivorous insects. Annu. Rev. Entomol. 28: 337–264.

Ridgway, N. M., and D. L. Mahr. 1986. Monitoring adult flight of *Pholetesor ornigis* (Hymenoptera: Braconidae), a parasitoid of the spotted tentiform leafminer (Lepidoptera: Gracillariidae). Environ. Entomol. 15: 331–334.

SAS Institute. 1989. SAS/STAT user's guide, version 6, 4th ed. SAS Institute., Cary, NC.

Schöller, M., S. Prozell, A.-G. Al-Kirshi, and C. Reichmuth. 1997. Towards biological control as a major component in integrated pest management in stored product protection. J. Stored Prod. Res. 33: 81–97.

Simmons, P., and H. D. Nelson. 1975. Insects on dried fruits. (U.S. Dep. Agric. Agric. Handb. 464.

SPSS. 1998. SPSS Base 8.0 user's guide. SPSS, Chicago, IL. [USDA] United States Department of Agriculture. 1998. Agricultural statistics. USDA, Washington, DC. [UNEP] United Nations Environmental Programme. 1992. Fourth Meeting of the parties to the Montreal Protocol on substances that deplete the ozone layer, Copenhagen, 23–35 November 1992. UNEP, Nairobi, Kenya. [USEPA] United States Environmental Protection Agency. 1998. Reregistration Eligibility Decision. Aluminum and Magnesium Phosphide. Cases 0025 & 0645. USEPA, Office of Pesticide Programs, Special Rev. and Reregistration Division.

Werner, J. J., and R. N. Williams. 1985. Observations on the development and behavior of *Zeteticonthus utilis* (Hymenoptera: Encyrtidae), a parasite of *Carpophilus* spp. (Coleoptera: Nitidulidae). J. Entomol. Sci. 20: 450–453.

Zettler, J. L., W. R. Halliday, and F. H. Arthur. 1989. Phosphine resistance in insects infesting stored peanuts in the southeastern United States. J. Econ. Entomol. 82: 1508–1511.

Received for publication 4 February 2000; accepted 3 May 2000.